NASA-CR-201936

7N-85-CR
68079

NASA Technology Utilization Program

A Summary of Cost Benefit Studies

- Prepared for -

Office of Technology Utilization
National Aeronautics and Space Administration
Washington, D.C. 20546

Contract NASW-3021

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December 1977

EXECUTIVE SUMMARY

The NASA Technology Utilization (TU) Program was initiated in 1963 to carry out the new technology reporting and dissemination requirements of the 1958 Space Act. Operational program elements for technology transfer include publications, Industrial Applications Centers (IACs), the Computer Software Management and Information Center (COSMIC), Application Teams, application engineering projects, and other activities such as TU conferences, special publications and technical interpretation assistance for potential users of NASA technology. These major program elements are directed toward two distinct audiences: the private sector (TU Information Systems), and the public sector (Applications Engineering Systems).

Congress first introduced the idea of conducting a cost-benefit study for the Technology Utilization Program in its FY 1977 NASA budget hearings and later specified this study as a firm requirement in its FY 1978 House Authorization Report.

In order to assess the feasibility of conducting such a study, the NASA Technology Utilization Office initiated two independent preliminary investigations in mid-1976 to develop and compare alternative cost-benefit analysis methods for the TU Program elements. It was determined that these two alternative methods, applied by the Denver Research Institute (DRI) and Mathematica, Inc., were compatible and provided a uniform basis for cost-benefit analysis across the broad and diverse range of TU Program activities.

This report summarizes the results of applying these two distinct methods for estimating benefits generated by the NASA Technology Utilization Program.

Study Methods

Cost-benefit studies rely on two types of estimation methods -- one for program costs and the other for program benefits. Cost estimates are usually based on the opportunity cost for program expenditures. In traditional economic practice, the standard method for estimating opportunity costs is to calculate the present value that program expenditures would have if they had been invested in the best available alternative to the program. The Office of

Management and Budget (OMB) recommends the use of a 10% rate of return for the best alternative investment. Costs for the TU Program presented in this report were estimated according to this method. They include both program personnel costs (i.e., civil service wages including the OMB-recommended 30% overhead rate) and authorized TU Program R&D funds. All analytic results in this study use 1976 as the base year for present value.

The two basic methods for estimating program benefits were:

(1) Consumer Surplus Model - Benefits were estimated based on demand analysis of individuals' "willingness-to-pay" for Program outputs they receive rather than forego these outputs.

(2) Financial Investment Model - Benefits were estimated from statistical analyses of random sample data indicating how much individuals were "willing-to-invest" in using Program outputs and the extent of gross benefits realized or expected from their investment.

The first of these study methods, the consumer surplus model, was judged to be readily applicable to those Program elements, such as applications engineering projects, that produce tangible output products or processes. In this situation, the user perceives a definite, predetermined level of utility and thus can affix an appropriate value to the product or process -- or, rather, a price which he is "willing-to-pay" for its use. Technical information on the other hand, cannot be immediately assessed in terms of its utility or economic value to the potential user. In this situation, the information recipient must invest time, an economic cost, to assimilate the information before its relevance and potential application can be determined. Therefore, the potential user of technical information operates in a speculative mode by risking a tangible resource (time, in this case) to determine the value or applicability of the information to his technical needs. Speculative financial investment is therefore an appropriate model for estimating private sector benefits from technical information provided through TU Program Information Systems.

Table I summarizes comparative characteristics of these benefit models as applied to the two basic TU Program types.

TABLE I. BENEFITS ESTIMATION METHODS

	Program Type	
Study Element	Information Systems	Adaptive Engineering
Program Activity	• Publications (e.g., Tech Brief) • Industrial Application Centers • COSMIC	• Application Teams • Application Engineering Projects
Primary Objective	Private Sector	Public Sector
Beneficiary	Industrial Firms	Consumers
Type of Benefit	Direct	Indirect
Benefits Measured	Net Profit	Societal Improvement
Benefit Model	Financial Investment (Willingness-to-invest)	Consumer Surplus (Willingness-to-pay)
Data Sources	Random Sampling of Direct Users	Expert Opinion & Secondary Sources
Method of Analysis	Statistical Aggregate	Demand Analysis

Data Collection

As indicated under Data Sources in Table I, the benefit estimation methods required two data sources. The data collection activity, initiated in mid-1976, required an extensive effort for each method.

In estimating quantitative benefits generated by TU Information Systems, over 700 in-depth interviews were conducted with users of NASA technology selected on a random sample basis. These interviews were conducted by ten different individuals in five participating institutions in accordance with a prescribed interview protocol. On the strength of the large random sample data set, this study represents by far the largest and most detailed cost-benefit analysis of the technology transfer process conducted to date. Prior studies of technology transfer have generally used non-random sample sizes of less than 100. Thus the rigorous statistical results from the present data set have a relatively high level of confidence (90%).

For TU Application Engineering Systems, little or no data was available for prices and quantities of the products or processes created by public sector application engineering projects. Therefore, it was necessary to generate a demand curve by indirect methods for each of the eight projects selected for study in 1976. This required a seven-step estimation process which ultimately provided an estimate of the costs saved by the consumers in general (i.e., society) in using project results as compared to cost of using an existing good or service, referred to as the baseline technology. Quantified data concerning such factors as: market size; possible rates of market penetration; cost savings relative to the baseline technology that would be realized if the NASA project technology were introduced into the market; and probabilities for successful market introduction were all estimated based on expert opinion obtained through in-depth interviews and secondary sources (e.g., The National Eye Institute).

Study Results

The data collected for each study method described above were analyzed to estimate the costs and net benefits, discounted at 10 percent to their 1976 value, for each of the four major TU Program elements. The results presented below are based on rigorous statistical analysis of random sample and other data at the 90 percent confidence level. The benefit, and benefit-to-cost ratio estimates are lower bounds for the TU Program in the sense that, with 90 percent confidence, the actual benefits, and ratios, are greater than the estimates given.

These figures are presented in Table II with benefit-to-cost ratios for each program element and for the aggregate totals. The benefit-to-cost ratio for the entire TU Program is at least 6:1, with the individual ratios ranging from at least 3:1 to at least 26:1.

As noted in Table II, these results are lower bound estimates of benefits attributable to the TU Program. In fact, several program activities, such as the Technology Use Studies Center and Application Teams, were not sampled for benefits due to time constraints. The lower-bound benefit estimates for the entire program, therefore, do not reflect all program activities although all of the costs of the program are included. It should also be noted that these program costs do not include the NASA R&D expenditures to develop the technology itself.

Further results, described in the summary report, show a very strong correlation between the expected net benefit per program transaction and the NASA unit cost to provide each transaction. A similar high correlation exists between expected net benefit and the user's investment per transaction. This indicates that value is being added to NASA technical information by the TU packaging process and that the technology transfer process is a rational economic investment activity. These qualitative relationships between user benefits and costs of adding value are widely believed to be true by information scientists. These relationships have been quantified as a result of this study, apparently for the first time. In addition, data from this study indicates that the return on investment model for technical information may provide basic insights for the small investment segment of the larger, aggregated investment activity at the national level.

TABLE II. SUMMARY OF COSTS AND BENEFITS DUE TO THE TECHNOLOGY UTILIZATION PROGRAM (1971 - 1976)

Program Element	Costs ($M)	Net Benefits* ($M)	Benefit-to-Cost Ratio*
Publications Program	10.9	135.6 - 151.8	12 :1 to 14:1
Industrial Application Centers	17.0	44.4 - 52.2	2.5:1 to 3:1
COSMIC**	1.7	43.5	26:1
Application Program**	32.3	133.6	4:1
	61.9	357.1 - 381.1	5.8:1 to 6.2:1 Aggregate Ratio

*Estimates are given as lower bound values

**Conservative lower bound estimate based on available, non-random data.

NOTE:

(1) All economic values are in 1976 dollars, discounted at 10 percent to 1976 present value.

(2) Total user benefits are those net economic gains produced through applications of aerospace technologies generated as a result of NASA R&D expenditures. Costs, on the other hand, include only those TU Program activity costs required to make the technology available to potential users.

In conclusion, the NASA Technology Utilization Program has been a very good investment of public funds. Further data collection and analysis should provide an even more precise estimate of actual benefits which probably exceed the lower bound benefit estimates reported here. More importantly, this cost-benefit study has developed appropriate models for understanding how the technology transfer process generates economic growth and social benefits from government-funded R&D. Moreover, it should become possible, based on this cost-benefit model, to predict economic growth that may be achieved from continued refinement and systematic development of NASA technology transfer activities.

SECTION I: INTRODUCTION

The NASA Technology Utilization Program, initiated in 1963 consists of a broad variety of program activities ranging from technical publications to technical assistance and adaptive engineering efforts. The requirement by Congress to conduct a cost-benefit study of these activities presented a basic methodological problem because no single cost-benefit analysis method was clearly appropriate for all program activities. This problem was due to the fact that Program activities are designed to achieve two distinct primary objectives:

- To facilitate the secondary use of aerospace technology in the Nation's private sector -- accomplished primarily through TU Information Systems, including publications such as Tech Briefs, Industrial Application Centers, and COSMIC, the computer software center; and

- To adapt, modify or otherwise reengineer existing aerospace technology to meet specified needs of public sector agencies and institutions -- accomplished through TU Application Engineering Systems, which includes Application Teams and application engineering projects.

This report integrates and summarizes the findings of two preliminary cost-benefit studies of the NASA Technology Utilization Program[1,2] and includes the final results of additional data collected and analyzed during CY 1977. The studies which form the basis of this summary report, which have been previously published, contain complete details concerning data sources, cost and benefit estimating methods, interviewing techniques, data quality control procedures and analytic methods.

Cost-benefit studies rely on two types of estimation methods -- one for program costs and the other for program benefits. Cost and benefit data attributed to TU Program activities from 1971 through 1976 were collected and analyzed. This particular time period was selected on the basis of data availability and the relative expense and uncertainty associated with the gathering of earlier data.

Two methods for estimating benefits were used in this study which relate directly to the two primary program objectives stated above and are described in detail in the section which follows. Program costs for both benefits estimation methods, however, were calculated using identical procedures.

Cost estimates are usually based on the "opportunity cost" for program expenditures. In traditional economic practice, the standard method for estimating "opportunity costs" is to calculate the present value that program expenditures would have if they had been invested in the best available alternative to the program. The Office of Management and Budget recommends the use of a 10 percent rate of return for the best alternative investment. Costs for the TU Program presented in this report were therefore estimated according to this method. These costs include both program personnel costs (i.e., civil service wages plus 30% overhead) and program R&D funds. All of the analyses use 1976 as the base year for present value.

The methodological problem occurs for the benefit estimation method and this issue was resolved by a preliminary investigation that compared two alternative methods.

The next two sections summarize the cost-benefit study methods, data collection, analysis methods and results for the major program elements related to each of the two objectives described above. The final section summarizes the conclusions, observations and recommendations from the TU Program cost-benefit study.

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[1] Anderson, Robert J., et al. A Cost-Benefit Analysis of Selected Technology Utilization Office Programs. Princeton, New Jersey: MATHTECH, Inc., Division of Mathematica, Inc., November 1977.

[2] Johnson, F. Douglas, et al. NASA Tech Brief Program: A Cost Benefit Evaluation. Denver: Denver Research Institute, University of Denver, May 1977.

SECTION II: TU INFORMATION SYSTEMS FOR THE PRIVATE SECTOR

The NASA Technology Utilization Information Systems include most of the known mechanisms for transferring technical information produced by aerospace R&D to potential users, primarily in the private industrial community. The major information-based program activities and their related products are:

- Publications - NASA Tech Briefs, TU Compilations, and, in cooperation with the Small Business Administration, the SBA flyers; Technical Support Packages (TSP's) are sent to individuals who request further documentation after reading one of these announcement mechanisms;

- Industrial Applications Centers (IAC's) - University-based services that prepare computerized searches of the NASA scientific and technical information base, together with other information bases, in response to requests from industrial clients; and

- Computer Software Management and Information Center (COSMIC) - A university-based dissemination center which specializes in making computer software and documentation available to industrial clients.

The number of transactions, where an individual or firm received one of the information products above, is quite large even for the limited time period between 1971 and 1976: over 300,000 TSP requests; over 15,000 retrospective searches by IAC's; 21,000 computer program documentation requests; and 1,200 computer programs requested. In this context, the selection of an appropriate method for reliable estimates of benefits due to these transactions presented a major problem in the initial phase of this study. Two fundamental questions were asked: (1) Is the information product a consumer good for which there is a predetermined intended use by the consumer who is relatively certain about its utility and how much this utility is worth to the consumer? or (2) Does the information product represent an investment opportunity for the user wherein there is a relative uncertainty regarding its application which can only be determined after the investment has been made? The initial step for the cost-benefit study was to examine these two questions in order to determine the appropriate methods for estimating benefits from TU Information Systems.

Study Method

The NASA TU Office initiated two independent preliminary investigations in mid-1976 to develop and compare the two basic methods indicated above for estimating program benefits. The first method, consumer surplus, was applied by Mathematica, Inc. to the Tech Brief Program, COSMIC and public sector application engineering projects. The second method, financial investment, was applied by the Denver Research Institute to the statistical aggregate for a random sample of TSP requests from the Tech Brief Program. This was apparently the first direct comparison in which both methods were applied to a single program (Tech Briefs) over a fixed time period (1971 through 1976).

The preliminary study results clearly indicate that technical information products represent investment opportunities to private entrepeneurs and individuals employed by firms. In other words, an individual must invest time (i.e., an economic cost to the employer or entrepeneur) in assimilating the information before its relevance, and possible application, can be determined. One example from the sample data illustrates the risk involved. A producer of educational devices invested about $10,000 to develop new product prototypes based on the design described in a NASA Technical Support Package. About $1,200 in prototype development costs were saved but the net benefit was a loss of $8,800 after the company concluded that the market was insufficient, and therefore production plans were cancelled. As illustrated by this example, there is an inherent risk associated with the information transfer process which is borne by the employer in order to obtain potential economic benefits, (i.e., net economic profit) by applying the new technology described in the information product received. Speculative financial investment is therefore an appropriate model for private sector benefits from technical information.

Similar benefit models are used to analyze investments in private R&D projects, the stock market and natural resources exploration. For these investment models, as the proportion of investment failures increases for the speculator (i.e., increased risk), the rate of return (i.e., net economic benefits) from each successful investment must also increase. Otherwise the speculator's total wealth will decrease over time.

In this context, the willingness-to-pay for a specific investment opportunity appears to be indirectly related to the expected return from the specific opportunity and directly related to statistical expectations for each type of investment (e.g., technical information, R&D facility, stock market membership or resource exploration lease). The statistical expectation for each of these factors apparently determine the willingness-to-pay for each type of investment opportunity: (1) Size of investment; (2) Rate of return; and (3) Risk, or variability, in the rate of return. The educational equipment firm described above, for example, continues to request NASA Technical Support Packages despite its $8,800 net loss experienced from one TSP, since the cumulative net benefit from all TSP requests by the firm has shown a very good return on its aggregate investment.

Data Collection

The preliminary study of the Tech Brief Program by Denver Research Institute was based on a random sample of user costs and benefits from 90 TSP requesters. The random sampling procedures and data collection methods, described in the published report for that study, were applied in 1977 to a much larger data collection effort. Over 600 random sample interviews were conducted in 1977 by ten individuals in five participating organizations. This effort was coordinated by the Denver Research Institute to assure a homogeneous interpretation and reliability for the entire data set from over 700 interviews. This represents the largest known random sample of interviews for detailed cost and benefit data from technical information recipients. Table III shows the TU Information System products sampled, the number of transactions for each product type and the sample size.

Although the sample sizes are small in comparison to the population sizes, they were calculated from a standard population proportion formula to achieve 90 to 95 percent confidence levels. In addition, the two statistical results for sample data were in the form of lower bound estimates at the 95 percent confidence level. The standard procedures used in calculating these lower bounds incorporate population and sample sizes, as well as the mean and variance in the sample data. It should be noted that at least one case in three of the TSP samples and two of the RSS samples had net benefits of $100,000 or more, and a case of this magnitude was obtained by six different interviewers.

TABLE III

Data Samples for Information System Products

Type of Information Product	Number of Transactions 1971 - 1976	Sample Size
TSP Request (1)		
o Tech Brief	56,900	180
o Tech Brief Journal	12,250	90
o TU Compilation	134,100	90
o SBA Publication	107,750	89
Subtotal	311,000	449
Retrospect Search (IAC) (2)		
o Level 1 (Reviewed Only)	7,000	103
o Level 2 (Interactive)	850	90
o Level 3 (Edited)	7,700	58
Subtotal	15,550	251
Computer Program (3) (COSMIC)	1,200	37
Total	337,750	737

(1) Samples were drawn from transactions that occurred in 1971, 1972, 1973, 1974 and 1976.

(2) Samples were drawn from transactions that occurred in 1976.

(3) COSMIC interviews were not part of the formal random sample but the data satisfy the general criteria for randomness.

The interview protocol, developed for the initial study in 1976, was expanded to obtain more refined data from the larger sample in 1977. These refinements related to questions raised in the 1976 results concerning such issues as how technical information reduces uncertainty in making decisions, how uncertain recipients are with regard to the benefits they might receive from technical information, what economic return they expect in general from technical information investments; and, how do the net benefits appear in the firm's accounts for purposes of taxation.

The three primary data points for all interviews were: (a) the estimated costs and gross benefits, distributed over time, that the user attributed directly to receiving a specific information package (i.e., costs and benefits that would not have occurred, in the interviewers opinion, without the information package); (b) the type of application achieved or expected for the technical information received; and (c) the estimated chance of success for expected applications. Applications were classified in four types, or modes:

Mode 0 - No application was or will be attempted and the user's investment was negligible;

Mode 1 - Technical information was acquired with more efficiency or less time (i.e., less user costs) from the TU Information System than from alternative sources for the same information;

Mode 2 - Economic benefits were realized, or are expected, from the user investing to apply the information content in improving a product, process or service; and

Mode 3 - Economic benefits were realized, or are expected, from the user investing to apply the information content in developing a new product, process or service.

Typical of users in Mode 1 was the recipient who spent four hours reviewing the information provided by NASA rather than the one week he estimated it would take to find the information elsewhere. A typical Mode 2 response was from one recipient who spent a week assimilating the information and applied it to reduce the weekly cost of performing a production line process by two hours. A typical Mode 3 response was from a Chief Engineer who spent two weeks applying the information in the development of a new process which would reduce future production costs by $50,000 annually. In this latter case, the NASA information was estimated to provide five percent input in the new process development, so the annual gross benefit attributable to the NASA technology was $2,500. Neither of the respondants in Mode 2 or 3 believed that the same information could have been obtained elsewhere.

Most of the gross benefit estimates were based on cost savings and thus satisfied the Federal guidelines directly. A few estimates from the interviews were based on sales increases but these were reduced to before tax profit increases only. For Mode 2 and 3 applications, only a portion (typically less than 10 percent) of economic benefits from a technological change was from NASA.

A few interviewers in each sample reported that they expected their annual benefits to continue into the future. In addition to asking when this benefit stream might terminate, two analytic methods were used to estimate different termination dates. In each method, the utility of technology described in a document was assumed to decline at some annual rate. The conservative approach used a fixed 10 percent rate of decline and the second approach used various rates depending on the rates of technological change in industrial sectors related to the application. The termination dates estimated by interviewees were closer to the dates estimated by the second analytic method. The two analytic methods for terminating future benefit streams produced two different benefit estimates for a few Mode 2 and 3 cases and, therefore, two estimates for total benefits from the TU Program.

The information transactions for COSMIC were not included in the formal random samples due to time constraints. Over 35 benefit estimates from COSMIC clients were available, however, for statistical analysis and these data satisified the general criteria for a random sample and fit the same types of statistical distributions as did the formal random sample data.

All cost and gross benefit estimates were converted to 1976 dollars and discounted at 10 percent to their present value in 1976. The net benefit was obtained for each case by substracting user costs from user gross benefits in each instance where both figures were quantified in the interview data. User benefits and costs were quantified in over 70 percent of the interviews as a result of an extensive effort to develop refined interviewing techniques. Through these efforts, the more normal 40-50 percent rate of quantification was improved upon significantly.

Statistical analysis was used to estimate the lower bound expected values for two types of distributions in the data: (a) the probability of achieving each application mode from an information transaction and (b) the expected net benefit from an application in each application mode. The modal probability distribution was analyzed from sample proportions for Mode 0 (95 percent confidence upper bound), Modes 2 and 3 combined (95 percent confidence lower bound) and Mode 1 (the remainder). This distribution was analyzed separately for each of the four publication program announcement mechanisms and each of the three retrospective search (RSS) product types for IACs. Interviewees that reported less than a certain chance of success for intended Mode 2 or 3 applications were allocated by assigning the interviewee's estimated chance-of-success to Mode 2 and 3 and assigning the remaining chance to an information investment loss in Mode 1 (e.g., if the interviewee reported a 25% chance of success in a Mode 2 application, this was counted as .25 for Mode 2 and .75 for a net loss in Mode 1).

The distribution of net benefit values was then analyzed to estimate the statistical expection (95 percent confidence lower bound) for each of the following data groups: negative net benefits in Mode 1; positive net benefits in Mode 1; and all net benefits in Mode 2 and 3. The latter analysis was performed separately for the basic product types (i.e., TSP requests, retrospective searches, and computer programs) because the data indicated that these distributions were probably not from the same population. The distribution of values in each case, however, fit the Lognormal distribution quite closely based on a point by point comparison of accumulated probability (i.e., Kolmogorov test).

Standard statistical formulas were then used to estimate Lognormal parameters, lower bounds (95 percent confidence) and expected values for the net benefits in each modal group for each product type. A lower bound for the expected net benefits per transaction was then calculated for each product type by multiplying the modal probabilities times the expected net benefit for each application mode. Since this calculation involves the product of two lower bound estimates at the 95 percent confidence level, the resultant confidence level for the product is 90 percent (95 percent times 95 percent). This analytical procedure was applied twice, once for the benefit estimates from each method for terminating benefit streams. This then produced a range in expected lower bound net benefits per information transaction.

After completing the primary analysis steps above, the expected user cost per transaction (using the same statistical methods) and the internal rate of return (IRR) calculated using the standard financial formula were also analyzed for approximately 100 cases in which the quantified costs and benefits estimates were non-zero.

In summary, the principal analytic results per transaction are in the form of expected lower bounds per information system transaction. These results include the expected net benefits, user costs (i.e., investment), and probability of Mode 2 or 3 applications.

Study Results

Total benefits for the three major TU Information Systems activities -- TSP requests, retrospective searches and computer programs -- were calculated by multiplying the total number of transactions for each information product times the expected lower bound estimate for net benefits per transaction. These results are presented in Table IV with the program costs and benefit-to-cost-ratios. The ratios range from at least 2.5:1 to at least 26:1 with an aggregate ratio of at least 7.5:1.

The IAC Program has the lowest ratio but this is probably due to the fact that, although all of the program costs were included, benefits from several IAC Program activities were not estimated. IAC activities excluded due to time constraints on data collection were current awareness searches and special projects as well as TUSC, a specialized IAC in Oklahoma. Even with these limitations, the IAC Program lower bound estimate indicates a favorable benefit-to-cost ratio. It should be noted that the expected net benefit for IAC searches is significantly higher than that for TSP requests.

TABLE IV. COSTS AND BENEFITS DUE TO NASA INFORMATION SYSTEMS: 1971-1976

Program	NASA Program Cost ($M)	Number of Transactions	Expected Net Benefit Per Transaction* ($)	Total Net Benefit* ($M)	Benefit-to-Cost Ratio*
Publication Program	$ 10.9			$135.6-151.8	12:1-14:1
o SBA Flyer		107,750	$ 110		
o TU Compilation		134,100	600-680		
o Tech Brief		56,900	560-640		
o Tech Brief Journal		12,250	850-960		
Industrial Application Centers	17.0			44.4-52.2	2.5:1-3:1
o Level 1 (Reviewed only)		7,000	1,230-1,390		
o Level 2 (Interactive)		850	1,380-1,880		
o Level 3 (Edited)		7,700	4,480-5,320		
COSMIC**	1.7			43.5	26:1
o Documents		21,000	400		
o Computer Programs (other than NASTRAN)		1,070	2,400		
o NASTRAN Program		130	250,000		
	$ 29.6			$223.5-247.5	Aggregate Ratio= 7.5:1-8.4:1

* Estimates are given as lower bound values.

** Conservative estimate based on available non- random data.

NOTE: All economic values are in 1976 dollars, discounted at 10 percent to 1976 present value.

In addition, the ratios in Table IV are for the net economic benefits compared to program costs and therefore represent TU Program evaluation ratios. However, when the net economic benefits are compared to total costs (i.e., program costs plus user costs), the resulting ratios represent an evaluation of societal gains due to the Program. Data on user costs are available only for IAC searches and publications. The societal ratio is at least 1.7 to 1 for IAC searches and at least 1.6 to 1 for publications, indicating a satisfactory total return to society from these two information systems.

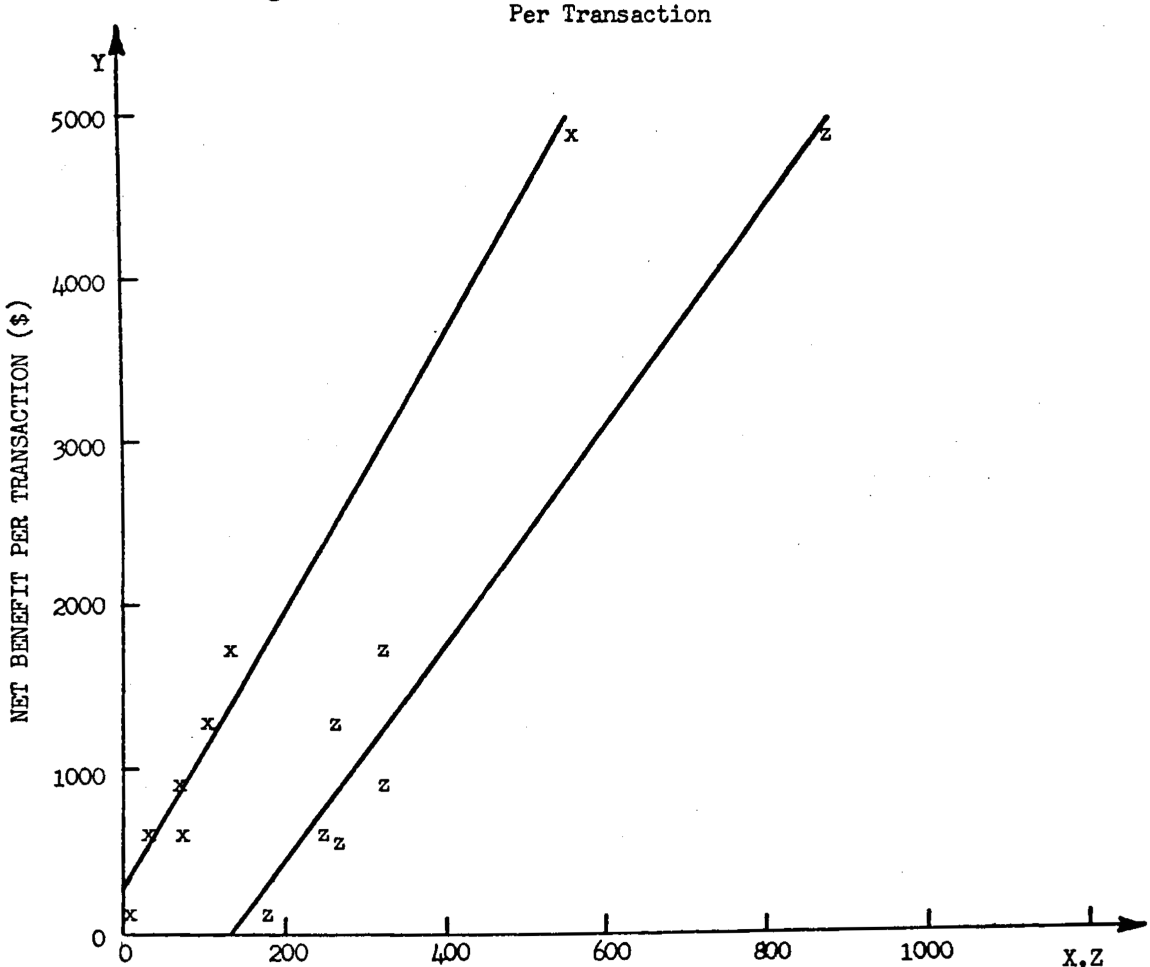
It should be noted that the net benefit values reported here are largely due to applying the content of technical information developed with NASA R&D funds. NASA Program Costs, however, are only those costs associated with the evaluation, preparation, and dissemination of TU information products to make NASA technology available to potential secondary users. Therefore, only the costs to facilitate secondary applications -- technology transfer function costs -- appear in the denominator of the benefit-to-cost ratios.

It should also be pointed out that large benefit-to-cost ratios should be expected for technology tansfer programs since only minor investments are typically needed to distribute and apply the technical content of information packages, although the content may represent a substantial public R&D investment and may generate substantial gross benefits. Benefit-to-cost ratios for traditional public investments such as water projects, however, should not be directly compared since these ratios include the total cost (e.g., costs of dam construction) required to provide the benefits.

A major question for any technical information service concerns how much potential value to the user is added by the production costs for the service. Another, closely related question concerns how much the user invests in information packages in comparison to the benefits obtained.

Figure I and Table V reveal a striking correlation in the random sample data between the expected net benefit per transaction and each type of cost (i.e., NASA production cost (x) and user cost (z)). The data points in each figure represent the aggregate, or expected, nets and costs for each product type rather than individual user estimates

Figure I. Correlations Between Net Benefits and Costs Per Transaction



NASA Production Cost (x): y = 8.5x + 300 (Corr. Coefficient = .99)
User Cost (z): y = 6.7z − 900 (Corr. Coefficient = .97)

TABLE V. Transaction Data and Probabilities

Type	Number of Transactions	Undiscounted Production Cost per Transaction (x)	User Cost (z)	Expected Net Benefit Value* per Transaction (y)	Probability for Modes 2&3 Actual Data	Probability for Modes 2&3 Lower Bound
Publications						
SBA	107,750	$ 2	$ 180	$ 110	.034	.002
TUC	134,100	30	260	640	.093	.043
TECH BRIEF	56,900	75	270	600	.090	.041
TBJ	12,250	65	330	910	.118	.062
IAC						
RSS-1	7,000	100	250	1,300	.087	.042
RSS-2	850	130	320	1,740	.163	.074
RSS-3	7,700	550	870	4,900	.313	.220

* In 1976 Dollars

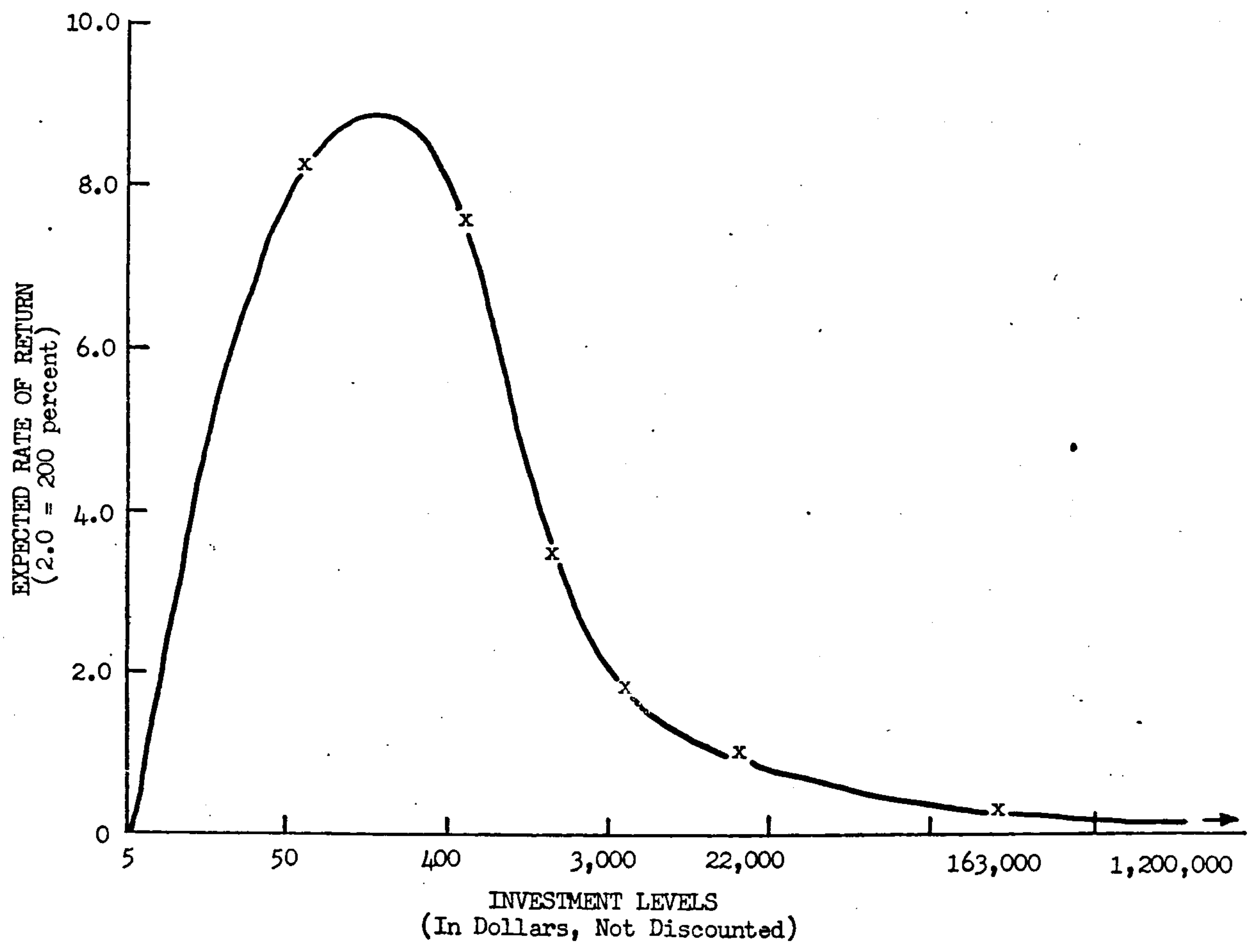
which have considerable variation. It should be remembered that the data were collected by 10 different individuals at five different institutions and each point in the figure represents at least one, and generally two, independent variables (e.e., modal probability for each point and expected net benefits per mode for basic product type).

During the interviews with TSP requesters, they were asked what gross benefit-to-cost ratio they expect to obtain when they invest in technical information, regardless of the specific nature or source of the information. The average response for three different data sets were about 3.5:1 for each data set, which means they expect the aggregate net benefit-to-cost ratio to be about 2.5:1. This ratio is nearly identical to the ratio obtained from dividing the expected net benefits (y) by the expected user costs (z) for the same three data sets (TU Compilation, Tech Brief and Tech Brief journal requesters). Thus, TSP requesters receive in the aggregate, about the rate of return they generally expect to receive from technical information although the variations among individuals and among specific TSP requests is very large.

Finally, the internal rate of return data for 101 random interviews provides one of the most fundamental results from the study. The investment amounts ranged from $6 to $418,000. The larger amount was attributed to a TSP that described a new, quantitiative ultrasonic device developed to do quality control inspections for the Space Shuttle main tanks. The requester is the quality control manager for a major metal products firm. He is having the device built for use as an in-house production line inspection unit. He estimated that his net benefit would exceed $300,000 over a nine year period and his IRR was calculated to be .3 (30 percent), a reasonable rate for new industrial processes with some risk.

The rates for the other 100 cases ranged from -8.9 (-89 percent) to 77.7 (7,770 percent). These data were grouped on the basis of how much was invested (i.e., six intervals of undiscounted costs were used). Each group was statistically analyzed to estimate the expected rate of return for the investment level related to the group (the largest rate of return in each group was not included in the analysis). The distribution of rates in each group fit a Lognormal distribution closely and this distribution type was used to obtain the expected value for IRR. Figure II shows the expected rate of return compared to the investment level for the grouped data.

FIGURE II. Distribution of Expected Rates of Return



To date very little data has been available for rates of return and risks for technology-related investments below $100,000. The figure indicates a significant increase in risk and expected rate of return as investment levels decrease, with a peak at about one engineering day (i.e., about $200 with overhead). The rates of return realized for incremental investments in technical information may be due to a nearly random process which apparently produces the relative stability observed for larger aggregates of investment activity ranging from R&D projects to production facilities.

SECTION III. TU APPLICATION ENGINEERING SYSTEMS FOR THE PUBLIC SECTOR

The NASA Technology Utilization Application Engineering Systems include application engineering projects as well as Application Teams with specific social problem areas such as medicine or transportation. For this study, only the application projects, which represent the major portion of program costs for this TU system, were analyzed to estimate benefits. All program costs, however, were included in the cost-benefit results.

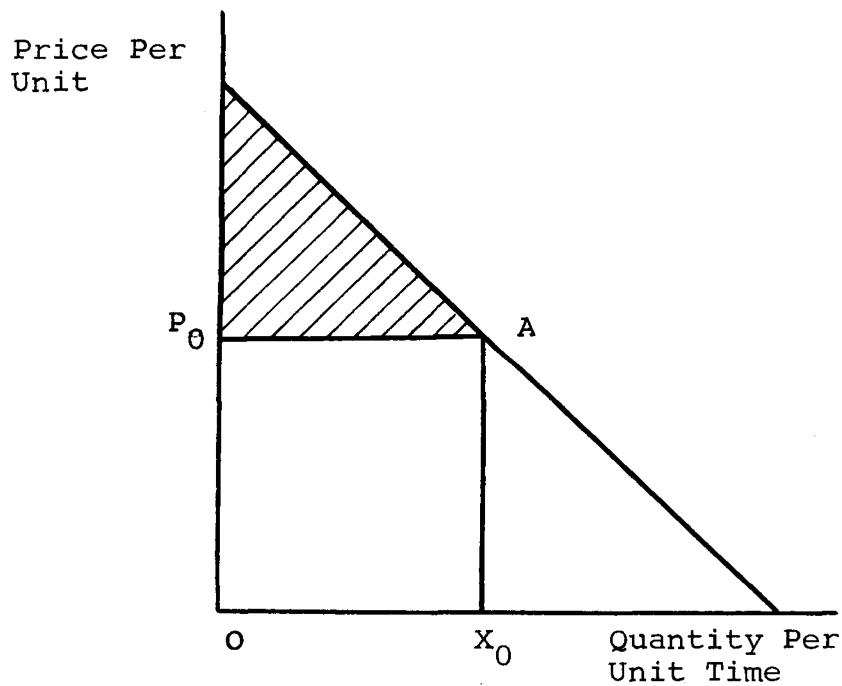
During the 1971 to 1976 time period, 135 projects were initiated. Most of these projects were cooperative efforts between NASA and at least one other governmental organization or public institution. Therefore, the social benefits from each project must be allocated to each funding source in order to determine those benefits attributable to the TU Program. As part of the 1976 preliminary cost-benefit study by Math Tech, a division of Mathematica, Inc., eight application engineering projects were selected for detailed analyses of costs and benefits on a project by project basis.

The consumer surplus method for estimating benefits was adapted by Math Tech for use in analyzing the total cost savings by society from the new product or process developed by each project. This microeconomic analysis first assumed that each of the project results was, or would be, successfully implemented as either a commercially available consumer good or as an institutionalized process depending on which of these goals the project has as its intended purpose. An improved firefighter's breathing system is an example of the former, and a new means for monitoring air quality by EPA is typical of the latter. The expected benefits for each of the eight projects were finally estimated by multiplying the benefits attributable to TU times the estimated probability of successful implementation. Complete details of the consumer surplus methods, data sources, and results are described in the published report for the 1976 Math Tech study. Only a general description of this study is presented below, together with the sub-sequent statistical analyses conducted as part of the current study to estimate societal benefits from the TU Application Engineering Systems.

Study Method

TU program cost estimates based on the opportunity cost method were described in the Introduction of this report. Therefore, only the consumer surplus method used for estimating benefits from TU Application Engineering Systems is described in this section. Benefits are estimated with the consumer surplus method by how much individuals' are "willing-to-pay" rather than forego the use of goods or services. Figure III shows the basic concept. The benefits to society, or consumer surplus, is the total amount that all beneficiaries would be <u>willing</u> to pay minus what they <u>do</u> pay for the goods or services. The shaded area in the figure represents the total benefits.

Figure III. Calculation of Consumers' Surplus



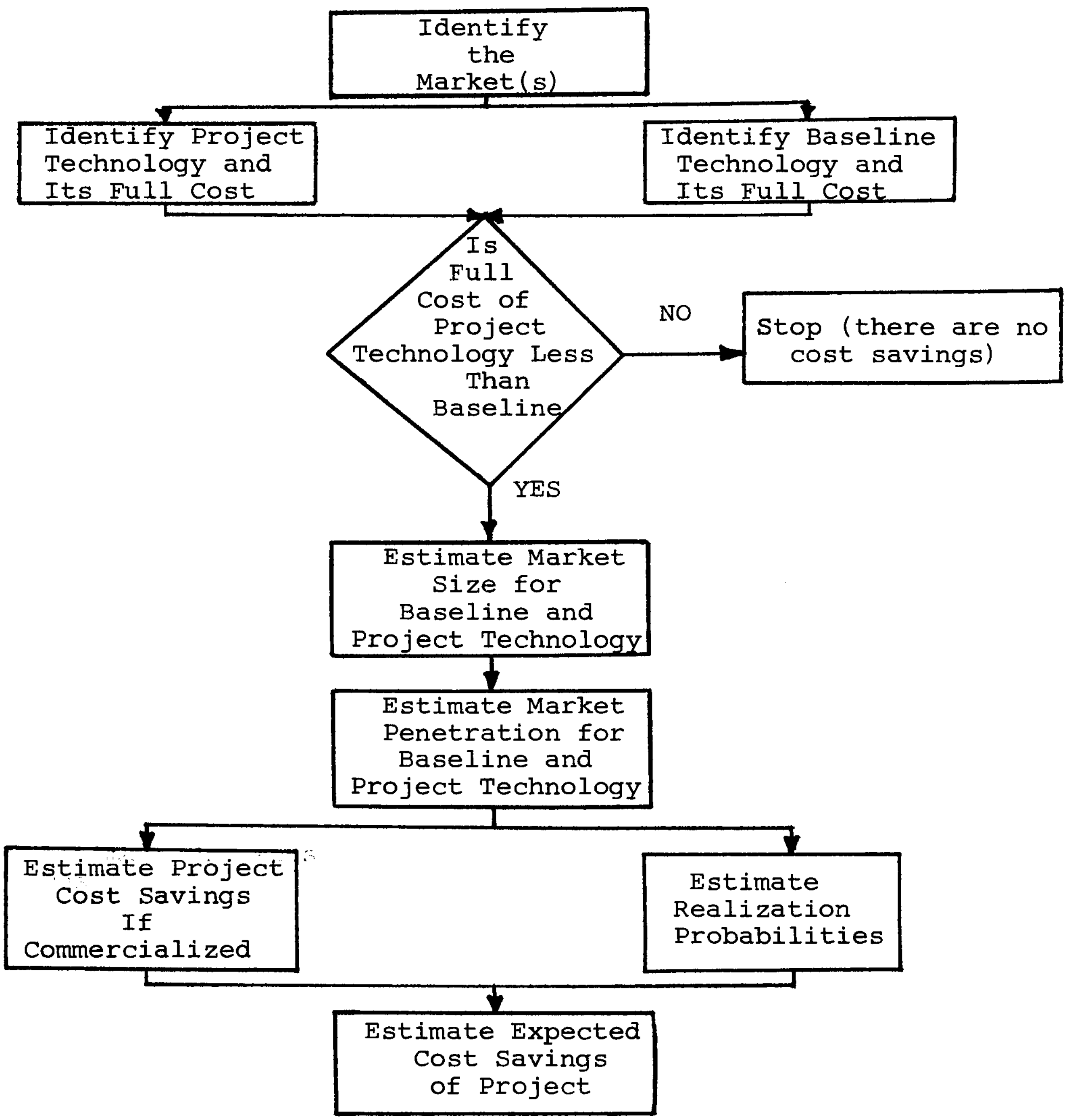
The application of this simple model to application projects however required a modification of this basic concept for the following reasons: (1) very little data on prices or quantities was available to create the necessary demand curve (the sloping line in Figure III), and (2) the total consumer surplus generated by every project could not be attributed entirely to the TU Program since other funding sources were involved. Therefore, two extensions of the basic model were required - - one that used cost savings to the consumer as a slightly conservative estimate for the actual consumer surplus, and one that estimated the proportion of benefits attributable to TU Program costs.

A seyen step process was designed to analyze the cost savings due to each of the eight projects selected for the study. Figure IV shows how this process was organized.

The key steps in this process were: (1) the comparison of consumer costs for the best existing consumer option (i.e., baseline technology) and the new consumer option created by the NASA project, and (2) the potential market size and the rate of penetration as some share of the future market when the project technology becomes available. This analysis provided an estimate for the total cost savings from each project as compared to baseline technology, assuming the project is economically successful as a consumer good or service.

Only a portion of benefits from each project, however, can be attributed to the TU Program funding. It was assumed that the project technology would be available eventually as a consumer good or service and that the TU funds simply accelerated the availability. The estimation of how much earlier this would happen as a result of the TU project provided the basis for estimating that portion of the total benefits from each project to be attributed to the TU Program. It should be noted that this method for estimating the TU benefits portion for a project is not directly related to the proportions of project costs paid by each project participant.

FIGURE IV. METHOD TO ESTIMATE COST SAVING BENEFITS



The next step in estimating TU benefits for these eight projects required the estimation of a probability of economic success for each project. The final expected benefit estimate for each project was then obtained by multiplying the TU benefits from successful projects times the probability of economic success.

The present study required that two additional analytic steps be performed in order to estimate the total benefits from all TU application projects: (1) estimate the expected benefit for a typical successful project, and (2) estimate the probability of success for a typical project. These parameters for the typical project were then applied to all TU projects initiated during 1971-1976.

The first estimate was obtained through statistical analysis of the TU benefit estimates obtained by Math Tech for eight selected projects. This analysis assumed that the project-derived goods or services would be available to the public. The second analysis required a careful assessment for each of the 135 projects, followed by the assumption that the economic success rate for government funded projects is generally lower than the average success rate for privately-funded R&D projects. The expected benefit for a typical project was finally obtained by multiplying the benefit per successful project times the probability of success.

Data Collection

The analytic methods described above were conducted on data obtained by Math Tech for each project from experts and secondary sources. The specific details concerning data and sources are completely described in the 1977 Math Tech report.

The three types of project-related information indicated in Figure IV can be summarized as: (1) technology and costs;(2) market; and,(3) success probability. Information concerning the project technology included a complete description of the performance characteristics for the TU project as well as existing, or planned, alternative technologies that provide the same basic function to consumers. The best alternative technology was designated the baseline for purposes of comparison with the project technology. In addition, technology-related data included the project development costs invested by NASA and other participating agencies, the expected (or actual) dates of consumer availability for both project and baseline technologies, and the full cost of each technology as a market good.

In some cases, the technology would be directly available as a consumer product and in other cases an intermediate organization would purchase the product to provide a consumer service at lower cost. For example, the cataract surgical tool could be purchased by hospitals to reduce the cost of removing cataracts -- this implies that some minimum number of cataract operations would be required for a hospital to justify the cost of the tool.

Market data were then collected to estimate market size and rate of future market penetration for the project and baseline technologies. This analysis included the cost of consumer goods based on each technology and the dates of availability. It assumed that market equilibrium would depend on these costs. The cataract tool, for example, would cost about $5,000 and the comparable baseline technology (an ultrasonic tool) costs about $25,000. The market, in this case, consisted of hospitals and eye clinics. The rate of penetration for each technology was the estimated number of purchases each year which such institutions would make from 1979 through 1988.

Cost savings for each customer were estimated from the costs for project and baseline technologies as alternatives to provide the same good or service. This figure, savings per customer, was combined with the rate of market penetration, number of customers per year, to estimate annual cost saving benefits for a ten year period after the project technology has been marketed. That portion of these total benefits attributable to NASA funds was then estimated from the availability date for the TU project-derived good as well as the development funds from both NASA and other sources.

Success probabilities were estimated from an assessment of each project's current status as well as average success probabilities for industrial R&D projects in three stages (i.e., technical completion, commercialization and economic success) and the estimated effect of factors such as government regulations and funding (e.g., Department of Health, Education and Welfare's Office of Occupational Safety and Health).

All 135 TU application engineering projects initiated between 1971-1976 were then reviewed by TU management to assess two factors for each project: current state of development (five steps ranging from technical feasibility to routine use); and the chance of success in completing the current development stage.

Study Results

The costs, benefits and success probabilities for the eight projects analyzed in the Math Tech study are shown in Table VI. Benefits attributed to the TU Program range from $100 thousand to $30 million assuming that each project would be successfully introduced as a market good or service.

These eight values were statistically analyzed as part of the present study. Although they were not a random sample of projects, neither the total benefits nor the TU portion of these benefits were available as even rough estimates before they the eight selected. The statistical distribution of these eight values was tested by the accumulative probability method described in the previous section. The test results indicated a close fit to the Lognormal distribution. A lower bound expected value was derived at a 95 percent confidence level for these data by using two standard formulas: (1) a lower bound based on small samples from a small population, and; (2) the expected value for a Lognormal distribution. This lower bound expected benefit per successful project was $4.5 million. This represents the best estimate that can be made from available data for the expected net benefits from a typical successful TU project.

The probability that a project will be successful was estimated to be between 22 and 34 percent. Table VII shows the number of projects at each stage of development with the chance for success at that level as they were assessed by TU management. The chances for success after the current development stage is completed were based on average industrial R&D project success rates which have been studied and reported by Drs. Edwin Mansfield and Samuel Wagner. Their study included success rates for three levels of industrial R&D projects: technical completion (57 percent); commercialization (65 percent of the completed projects); and economic success (74 percent of the commercialized project results). The chance that an R&D project will successfully complete all three levels (i.e., economically successful) is the product of these three factors, or 27 percent. However, when a mixture of projects at different development states is being analyzed, the fact that some are technically completed and some are even commercialized already must be included in the analysis. When this was done using Mansfield and Wagner results for the 135 application engineering projects, the chance of economic success was calculated to be 34 percent.

TABLE VI. SUMMARY DATA FOR EIGHT APPLICATIONS ENGINEERING PROJECTS.

Projects	Probability for Benefits	TU Costs ($M)	Total Costs ($M)	TU* Benefits ($M)	Total* Benefits ($M)
Biomedical:					
• Cataract Tool	50%	.155	.444	12.8	62.0
• Burns Diagnosis	50%	.220	.275	3.6	5.4
• Meal Systems	10%	.132	.285	8.0	105.0
• Heart Pacemaker	100%	.162	8.228	.7	72.0
• Human Tissue Stimulator	30%	.271	(3)	8.7	1,720.0
Engineering:					
• Nickel-Zinc Battery	50%	.220	20.728	30.0	656.0
• Track-Train Dynamics	20%	.007	13.433	.1	490.0
• Firefighter's Breathing System	100%	.840	1.169	3.0	6.1

* Benefits estimated by Consumer Surplus method assuming that the project results are successfully utilized.

NOTES: (1) All economic quantities are in 1976 dollars, discounted at 10 percent to present value in 1976.

(2) The MATHTECH analysis included one Applications Team project (zinc-rich coatings) which was not directly funded as an Applications Engineering Project. Therefore, the estimated benefits ($14.6 million) for this project were not included in the present analysis and this exclusion reduced the analytic results in the present study.

(3) Not directly estimated, analysis based on similarity with pacemaker project.

TABLE VII. Probable Success for 135 Projects (1971–1976)

Mansfield Wagner Results

.57 .5

.65 .5

.74 .5

PROJECT DEVELOPMENT STAGES		CHANCE OF SUCCESS IN STAGE 0%	30%	50%	80%	100%	Total (%)
1	Technical Feasibility	15*	2	1	2	0	20 (15%)
2	Prototype Development	3	1	3	2	1	10 (7%)
3	In-House Tests	0	6	11	5	3	25 (18%)
4	User Field Tests	0	1	10	8	2	21 (16%)
5	Routine Use	0	1	4	9	45	59 (44%)
6	Economic Success						
	Conservative:	0	0	3	5	22	30 (22%)
	M-W Results:	0	0	5	7	34	46 (34%)

* Number of projects with this probability of success (column) and at this stage of development (row).

These projects however were partially public-funded rather than wholly private-funded as were those in the Mansfield and Wagner study. The probabilities for success at each level were therefore reduced to 50 percent, or an even chance for success of failure at each level. It should be noted that there is an increasing difference from one level to the next between the Mansfield-Wagner average and the 50 percent chance assumed for TU projects. These differences correspond to an increasingly conservative estimate as the decision-making process moves further away from TU management. Using this conservative approach for the 135 projects, the chance of economic success was estimated to be 22 percent as compared to the 34 percent based on Mansfield-Wagner results.

The estimate above for expected net benefits per successful project was then multiplied by each of the two chances for economic success. This provided two estimates of lower bound expected net benefits per TU project ranging from $990,000 to $1,530,000. Only the more conservative 22 percent chance, or lower bound, was used to estimate total benefits from all TU Application Engineering Systems projects. Table VIII presents the cost and benefit estimates for these TU Program activities. The resultant ratio of 4:1 does not include any benefit estimates for Application Teams although these program costs are included in the denominator.

This conservatively estimated benefit-to-cost ratio for TU Program activities directed toward public sector benefits indicates that this is a good public investment. However, further data collection and analysis, particularly for the Application Teams, would increase the precision of these estimates and would thus probably increase the overall benefit-to-cost ratio for these programs.

Finally, it is interesting to note that benefit estimates for TU applications engineering project when compared with costs appears to follow the same correlation that is shown in Figure I.

In order to make this comparison, the undiscounted NASA production costs (x) were used here as they were in the figure. The average undiscounted cost for the eight projects analyzed was $206,000. When this program investment cost is used in the correlation line equation ($y=8.5x + 300$), the corresponding net benefit per project (y) is $1,751,000. This result is surprisingly close to the $1,530,000 expected net benefit per project estimated above using the Mansfield-Wagner success rate $34 percent) and twice the $990,000 expected net benefit per project used to obtain the 4:1 ratio above. Therefore, the application engineering project activity might presently be as cost effective as the other TU Program activities in terms of the value added by program funds.

TABLE VIII. Costs and Benefits Due to NASA Application Engineering Projects (1971-1976)

Program Cost	$32,300,000
Number of Projects	135
Average Cost per Project	$ 240,000
Estimated Benefit per Successful Project	$ 4,500,000
Estimated Probability of Success	.22
Expected Benefit per Project	$ 990,000
Estimated Total Benefits	$133,600,000
Benefit-to-Cost Ratio	4:1

Economic quantities are in 1976 dollars, discounted at 10 percent to present value in 1976.

SECTION IV: CONCLUSIONS, OBSERVATIONS AND RECOMMENDATIONS

The primary results of this study are the ratios of net benefit lower bounds to program costs for the entire TU Program and for each of the four major activities within the Program. The Program benefit-to-cost ratio is at least 6:1, and the four sub-ratios range from 3:1 to 26:1. This indicates that the TU Program is providing at least $6 in net economic return for each $1 invested in the Program.

Perhaps the greatest significance of the study, however, lies in the potential application of its results to a better understanding of the technology transfer process. Many technology transfer specialists have believed that an increased ability to measure and relate the many and varied transfer factors could lead to the application of systems analysis techniques for improving the process and its resultant economic benefits. The results of this study indicated that this goal might now be achievable since the transfer process is apparently more rational and predictable than was previously believed.

The NASA Technology Utilization Program can be characterized as a public investment which creates net economic growth by facilitating the secondary application of existing technology. The strong correlation, shown in Figure I between net benefits and production cost (i.e., NASA investment of public funds) is an extremely important factor in understanding how TU adds value to technical information through various packaging processes even though the resultant information products may be dissimilar. As these data are analyzed in greater detail and further random sample data are collected, it is expected that the ability to predict and manage program costs and benefits may increase substantially.

Effective technology transfer, however, requires that potential users of technology must also invest in the process in order to realize the potential benefits that may result from its use. Again, it is clearly shown in Figure I that user costs (i.e., private investment) have a strong correlation with expected net benefits.

Another significant observation from the study results is the important role played by the variety of transfer mechanisms available through the NASA Technology Utilization Program. The broad and diverse array of program elements, each with their own level of added value, provide users with a range of information product alternatives and investment levels from which to choose. In this context, the location of both correlation lines in Figure I when the costs are near zero is also of interest. The production cost line (x) indicates that some net benefits (about $300) might still be realized from NASA technical information if there were no TU Program; however, the expected net benefit would be very small and probably not worth the investment to many people. This is supported by the user cost line (z) which indicates that approximately $200 of user investment (or approximately one engineering day) would be required to generate this expected net benefit of $300. Thus the user's benefit-to-cost ratio would be 1.5:1, or less than the user's expectation of 2.5:1 noted earlier in Section II.

The public investment in the NASA Technology Utilization Program is apparently necessary in order to increase the probability for successfully transferring aerospace technology which, in turn, stimulates U.S. economic growth. In contrast to this public investment, private firms which invest in R&D to develop new technology weaken their economic position if they make the new information freely available to competitors without charging a fee to apply the information (e.g., patent license royalties). If a competitor could freely apply the same information to achieve similar gross benefits, the competitor's internal rate of return would be much higher than the original firm's rate. The difference in rates would be due to the high R&D cost for the first firm to develop the original technogy compared to the relatively low adaptation costs for the competitor. This is comparable to the high rates of return for secondary users of NASA technology except for higher risks due to the uncertain utility of aerospace technology in non-aerospace applications. The TU Program investment reduces that uncertainty by screening and evaluating the aerospace technology thereby increasing the economic value of this technology.

Another observation concerning the unit production cost correlation is related to the technology utilization objective. Since the probability for Modes 2 and 3 (i.e., tangible application of the technical content) is closely related to the expected net benefit per transaction, this probability is also strongly correlated with production costs. This provides a basis for understanding one of the key trade-offs in allocating transfer program resources to program activities -- increasing the resource allocation to activities with higher probability for Modes 2 or 3 applications.

This management trade-off can be illustrated by an example. If two application engineering projects each with a 50 percent chance of success for Modes 2 or 3 applications, cost the same as 1,000 information products, each having a five percent chance of success in Modes 2 or 3, we could expect to achieve either one successful project application <u>or</u> 50 successful uses from the information products from the same Program funds. In terms of total number of applications, the second option would be better. However, if the expected net benefit per successful project is $1 million and the expected net benefit per successful information product application is $20,000, both options would then generate a total expected benefit of $1 million.

In summary, the cost-benefit study results reported here, when combined with the results from a current on-going study of technology classification methods, are expected to provide a quantitative basis for better predictions of the transfer process. This would provide TU Program management with better answers to questions such as what technologies are the most useful to different economic sectors, which transfer mechanisms are the most cost-effective in different situations, and how much economic benefit can be expected from different transfer activities. This kind of management information could then be used to increase the TU Program benefit-to-cost ratio above its current high level of 6:1.